EFFECTS OF SUPPLEMENTARY NITROGEN ON BIOMASS AND NITROGEN ACCUMULATION IN THE SUNDEW *DROSERA CAPENSIS* L.

by

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1. Acknowledgements

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4. ABSTRACT

The effect of nutrient supplementation on biomass and nitrogen accumulation in the insectivorous plant *Drosera capensis* L. was studied under laboratory conditions using supplementary feeding of ammonium chloride (NH_4Cl) to plant leaf surfaces. The nitrogen solution used was based on a standard concentration of 157.6 mM NH_4Cl. *Drosera capensis* did not differ significantly in biomass or nitrogen accumulation from concentrations of 50%, 75%, 100%, 150%, or 200% of nutrient fertilizer when applied to the foliage. Reproductive structures were observed in higher numbers in those plants treated with higher concentrations of NH_4Cl but no relationship was found between reproductive structures and biomass or nitrogen concentrations. The results of this experiment potentially indicate that *D. capensis* can grow and initiate reproductive structures without additional nutrients above which already exist in the soil mixture. The results also suggest that *D. capensis* does not readily absorb NH_4Cl through its leaves.

Keywords: *Drosera capensis*, nutrient supplementation, biomass, nitrogen accumulation.

5. INTRODUCTION

5.1 Insectivorous plant perspective

The kingdom *Plantae* consists of five phyla. *Anthophyta* represents the largest and most diverse phylum, containing approximately 235,000 species (Raven *et al.* 1999). A small group of plants within this phylum, consisting of approximately 538 species occurring in 18 genera and 8 families worldwide, are known as insectivorous plants (Givnish 1989). Insectivorous plants are also referred as carnivorous plants, however, for the purpose of this thesis, the term insectivorous will be used and the term carnivorous will only be referred to in the context of cited literature. Insectivorous plants have been known to grow in nutrient poor environments where readily available nutrients are limiting. It has often been proposed that these plants fulfill their basic nutrient requirements by insect prey capture. This benefit is generally believed to be an effect of mineral nutrient uptake from prey, mainly nitrogen and phosphorus (Hanslin and Karlsson 1995).

However, some researchers question the reliability these plants have on the capture of prey for fulfilling such nutrient deficits (Chapin and Pastor 1999). Insectivorous plants have adapted to their unfavorable conditions by growing slowly. These plants function as a normal plant would but do not require a high supply rate of mineral nutrients from the soil due to the ability to store and re-utilize nutrients efficiently (Adamec 2002). Roots of most insectivorous plants are weakly developed but have the ability to regenerate quickly and withstand anoxic conditions (Adamec 1997). The capacity for nutrient uptake by roots is limited, and compensated by nutrient uptake from prey capture in modified leaves or traps (Adamec 1997). Nutrient uptake by

insectivorous plant leaves are either signaled by prey capture or nutritive stimulation and generally are aided by digestive enzymes then reabsorbed through specialized stalked and/or sessile glands (Slack 2000).

By definition, an insectivorous plant must meet two requirements. First, it must have the ability to absorb nutrients from captured prey and gain some benefit of fitness in terms of growth or reproduction. Second, the plant must have some obvious adaptation or resource allocation whose primary result is the active attraction, capture, and digestion of prey (Givnish 1989). Consequently, this definition implies that these plants will benefit nutritionally from insectivory.

Although there have been studies conducted on the effects of supplementary feeding in insectivorous plants, both positive and negative results have been documented. Adamec (2002) showed an increase in plant growth and nutrient accumulation in *Drosera capilleris* Poir., *D. aliciae* Hamet., and *D. spathulata* Labill. through supplemental foliar feeding using a nutrient solution consisting of NH_4NO_3, KH_2PO_4, $MgSO_4$, $CaCl_2$ and $FeCl_3$. Similarly, in a study of supplementary feeding on three *Pinguicula* species in the subarctic, Thoren and Karlsson (1998) found the plants exhibited an increase in growth when fed extra nutrients. On the contrary, Stewart and Nilsen (1992) found that nutrient supplementation decreased vegetative growth in *D. rotundifolia* L., suggesting this species had optimally adapted to low nutrient environments and any nutrient enhancement actually produced a toxic effect. To complicate the issue further, Chapin and Pastor (1995) found that *Sarracenia purpurea* L. did not increase in biomass from nutrient supplementation but had significant increases in nutrient concentrations within plant tissues.

5.2 Rationale

We selected *Drosera capensis* as a model plant for this thesis. *Drosera capensis* is a native insectivorous plant of the Cape peninsula in South Africa, and is one of the easiest *Drosera* species to cultivate under greenhouse conditions (D'Amato 1998). This particular genus of insectivorous plants has shown positive, negative, and neutral effects to nutrient supplementation on biomass and nitrogen accumulation in previous experiments (Adamec 2002; Hanslin and Karlsson 1995; Karlsson and Pate 1992; Stewart and Nilsen 1991). The diversity of effects from nutrient supplementation found in various *Drosera* species provides an opportunity to explore these differences within the genus *Drosera* and determine how the effects of nutrient supplementation on another *Drosera* species compares to the other species studied in this genus.

5.3 Objective

Our objectives of this study were 1) to successfully grow *D. capensis* in media under laboratory conditions and 2) determine if nitrogen supplementation treatments to the foliage under different concentrations has any significant effect on plant biomass and total nitrogen accumulation within the tissues of *D. capensis*.

6. MATERIALS AND METHODS

6.1 Plant Material, Media, and Lighting

Drosera capensis is a herbaceous perennial insectivore from the plant family *Droseraceae*. The leaves form around a center stalk with total length of petiole and leaf extending between 3 and 6 inches. The leaf develops two types of glands found on the adaxial side of the leaf. The first gland is a stalked gland used in the capture of prey, release of digestive enzymes, and most of the digestible material. The second gland is a sessile gland found on the leaf surface, and together with microscopic hairs, is used to a small degree for aiding in the re-absorption of digestible materials (Slack 2000; Givnish 1989).

Forty- five *D. capensis* specimens from an identical seed source were grown in 4" square containers using a soil mixture consisting of 60% peat (Premier Sphagnum peat moss), 25% #4 washed sand (Kodies sand pit, Prince George, BC), 10% 2-3mm Forestry sand (Target products, Abbotsford, BC) and 5% perlite (Supreme perlite, Portland, Oregon). Ambient nitrogen in the peat was 2.5 ppm or 0.00025 % (analysis provided by Premier Horticulture dept.).

From 45 plantlets, 36 of the most homogeneous appearing plantlets were selected for the experiment. Plantlets for all treatments were of relative equal size averaging six leaves and a length of 4cm per leaf. At that stage, 3 plantlets were dried and measured for initial biomass; the average dry weight of a plantlet was 0.024g. Plant containers were placed on germination trays covered with clear raised dome plastic lids. Lighting was provided in a floral light shelf system with a photoperiod of 16 h light and 8 h dark (fig. 1). Light intensity averaged 41.32 μmol $m^{-2}s^{-1}$ throughout the lighting system.

Temperature ranged between 20-25°C for the duration of the experiment. Plants were watered with reverse osmosis (RO) water to eliminate additional nutrient effects from tap water.

Figure 1. Floral light shelf with random arrangement of treatments in plants.

6.2 Nutrients

We used Chapin's nitrogen solution, based on an analysis of collected houseflies that showed nitrogen to be approximately 9% by mass. A solution of 157.6mM of NH_4Cl was created in an attempt to simulate this percentage into a working form. This solution was used in a previous supplement feeding experiment on *Sarracenia purpurea* (Chapin and Pastor 1995).

Table 1 illustrates treatment number and application concentration for fertilization of *D. capensis* leaves based on Chapin's standard concentration of NH_4Cl (157.6mM = 8.4 mg/L).

Table 1. Fertilization concentrations (NH_4Cl) for nutrient applications to *D. capensis*.

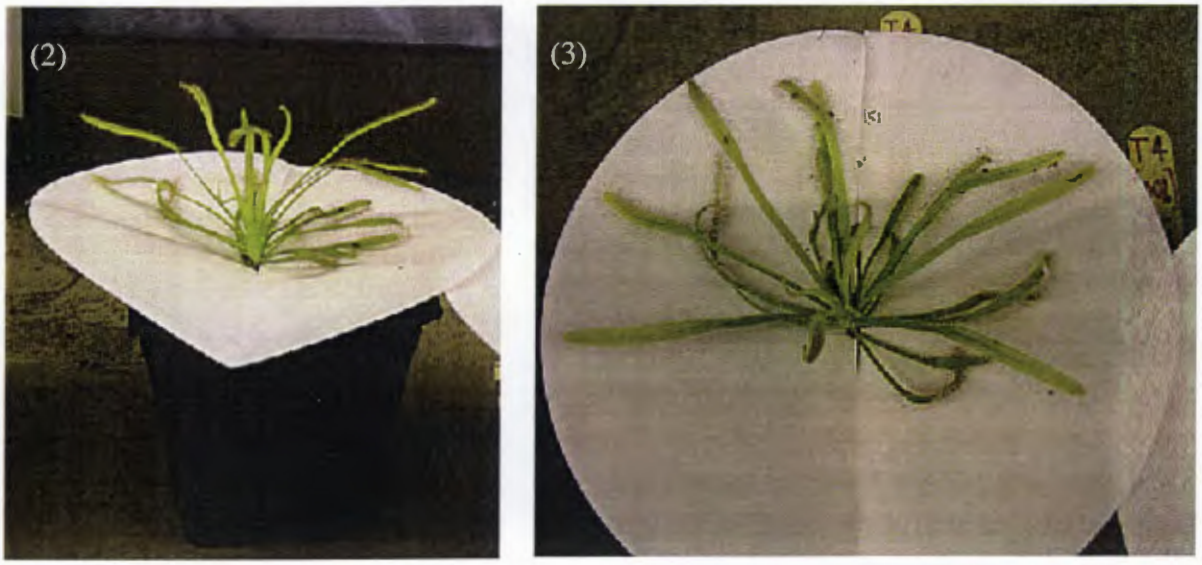
	Treatment	Concentration
1	Control	0 mg/L
2	50% of standard	4.2 mg/L
3	75% of standard	6.2 mg/L
4	100% standard	8.4 mg/L
5	150% of standard	12.6 mg/L
6	200% of standard	16.8 mg/L

6.3 Sample Design and Fertilization Regime

Thirty-six plants were divided into 6 treatment groups, each consisting of 6 plants and numbered accordingly. Plants were then set up in a random block design and moved on a biweekly rotation (mid rows to outer rows) to eliminate edge effects.

Calibrated spray bottles were used to apply nutrient fertilizer to the foliage of the plants. Each bottle dispensed approximately 0.82 ml of liquid per spray. Through preliminary trials, it was found that approximately 50% of the spray would stick to the leaves, and 2 sprays per plant (a total of 0.82 ml hitting the leaf surface) during each application period would sufficiently cover plant leaf surfaces. Plants were tilted at a 45° angle and sprayed from a distance of about 10 cm. Filter paper stem collars were placed at the base of each plant, exposing only the leaves during fertilization, to eliminate fertilizer from entering the media (figs. 2-3). Plant trays were covered with a plastic dome lid to prevent flying insects from being captured. Some fungus gnats were

observed in the media randomly among trays, any mature gnats that did become trapped on leaves were quickly removed.



Figures 2-3. Spray collars around plants to prevent soil fertilization.

Nutrient supplementation extended over a 4 month period (May 1/02 to Sept. 1/02) with treatments occurring every two weeks for a total of 8 applications per plant. Over the 4 month period, observations of growth within each treatment were recorded. At the end of the treatment period, plants were carefully harvested and separated into leaves and roots. All plant parts were dried at 70°C for 48 h. Dry weights were recorded from each plant to determine biomass of each treatment. Leaves and roots were ground separately. Leaves were ground using a Wiley mill and roots were ground using a mortar and pestle. Each sample was stored separately in glass sampling containers at room temperature until nutrient analysis. Total nitrogen and carbon concentration of leaf and root tissue was determined using Micro-Dumas combustion (NA1500 C/H/N Analyzer, Carlo Erba Strumentazione, Milan). Thirty six leaf and 36 root samples were processed

separately in 5 mg samples. The frequency of reproductive structures (flowering scapes) was recorded.

6.4 Statistical Analyses

Single factor ANOVA (excel version 5.1) were performed to assess significance between fertilization treatments in terms of biomass and nitrogen accumulation.

7. RESULTS

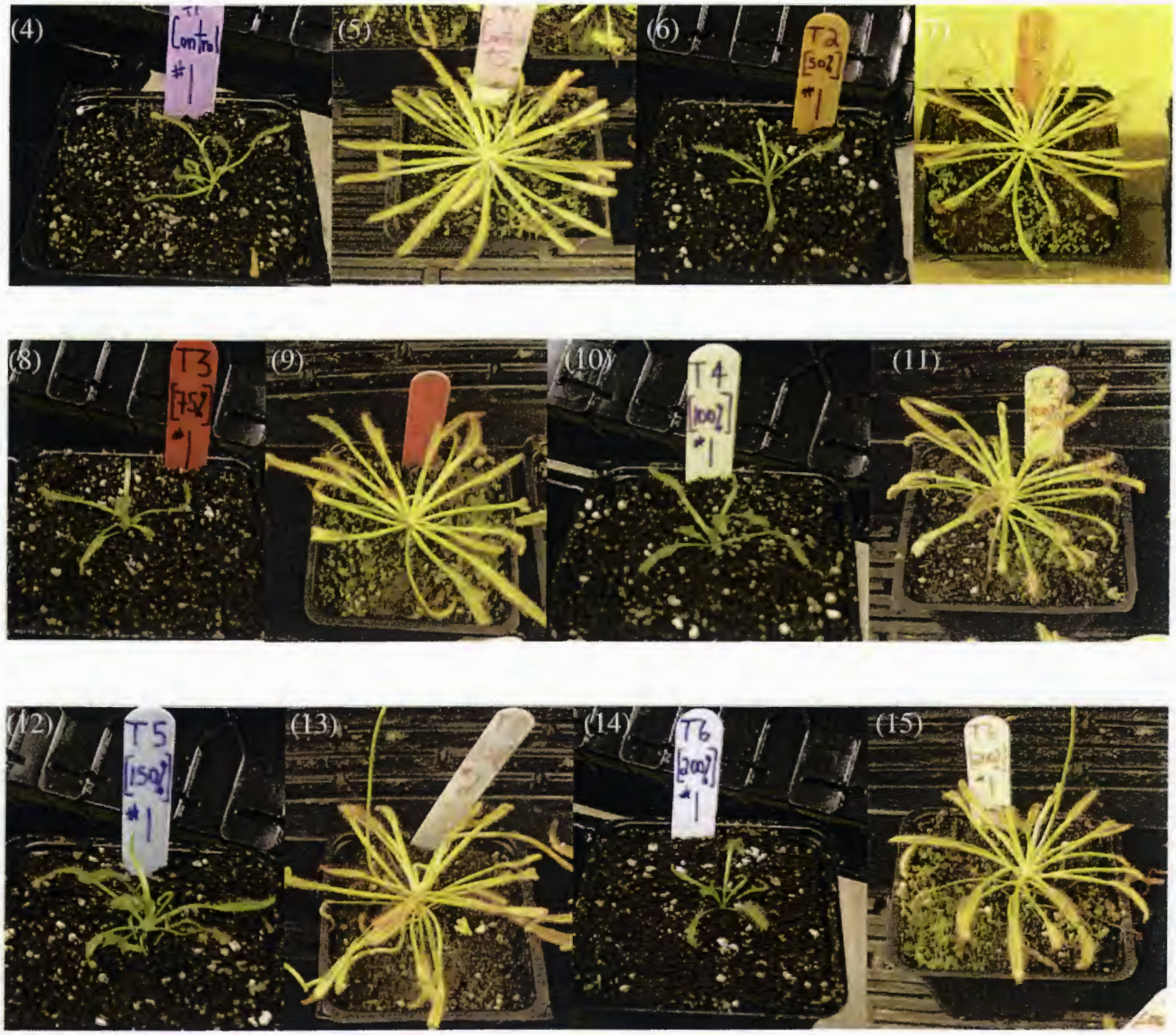
7.1 Cultivation and Morphology

All 36 plants selected grew successfully in the media provided over the 4 months of the experiment. There were no treatment effects on the visual aspect of the plants except in week eight, 2 plants from treatment 5 appeared to lose turgor and show signs of yellow discolouration. In terms of number of leaves, plants exhibited an increase over the period of the experiment, ranging from 6 to 33 (control) and 6 to 23 (treatment 6). The presence of flower stalks in all treatments was noted (Table 2). Figures (4-17) show the initial and the final condition of plants for each treatment.

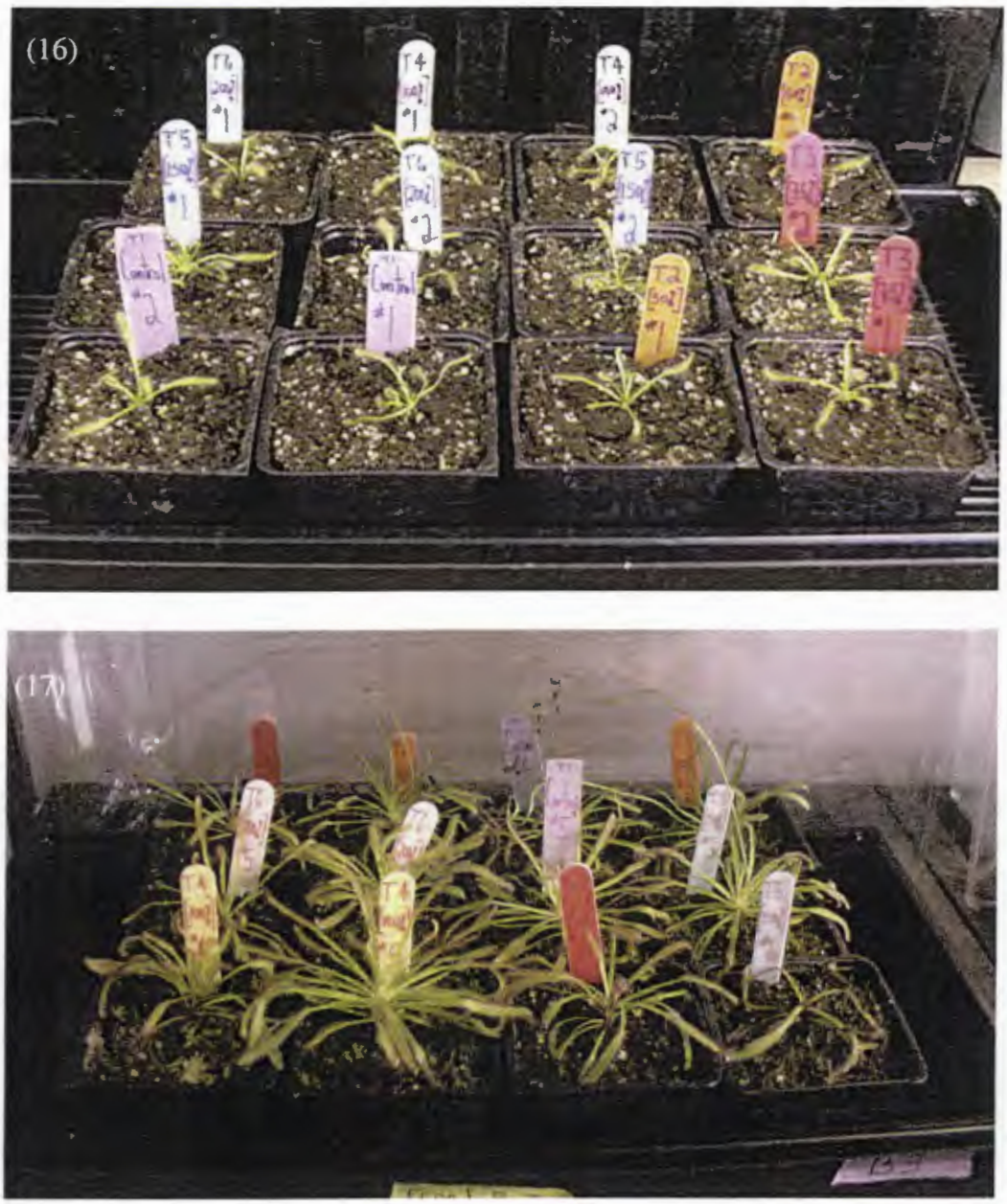
Table 2. Average initial (I-leaf) and final (F-leaf) leaf numbers, total number of flower stalks (TFS) grown, total number of flower stalks aborted (TFA), and total number of flower stalks which flowered (FSF).

Treatment No.	I-leaf (n=6)	F-leaf (n=6)	TFS	TFA	FSF
1: Control	6 ± 0.3	33 ± 1.0	2	1	1
2: [50%]	5 ± 0.5	28 ± 0.7	3	2	1
3: [75%]	6 ± 0.3	24 ± 0.5	1	0	1
4: [100%] standard	7 ± 0.2	30 ± 0.9	4	0	4
5: [150%]	7 ± 0.0	26 ± 0.7	4	1	3
6: [200%]	6 ± 0.2	23 ± 0.9	4	1	3

Note: Flower stalks aborted = stalks which senesced before producing flowers
Flower stalks flowered = stalks which flowered (alive or dead at end of trials)



Figures 4-15. Initial and final plant morphologies (representatives of each treatment). Treatment 1 (figs. 4-5); treatment 2 (figs. 6-7); treatment 3 (figs. 8-9); treatment 4 (figs. 10-11); treatment 5 (figs. 12-13); treatment 6 (figs. 14-15).



Figures 16 and 17. Initial plantlet size and randomization (Fig. 16) prior to experimental treatments. Final plant size and randomization (Fig. 17).

7.2 Biomass (dry weight)

At time of harvest, plants averaged an increase of 1.49 g in dry weight over four months of growth. Combined total leaf and root biomass ranged between 1.24 g (treatment 5) to 1.72 g (treatment 4). The average shoot, root, and total biomass of each treatment are shown in Table 3. Supplementary foliar feeding did not result in any significant differences at the 0.05 level in leaf biomass ($p = 0.347$) or root biomass ($p = 0.489$).

Table 3. Average leaf, root, and total plant biomass (dry weight ± SE) from each treatment, n = 6 per treatment.

Treatment No.	Leaf biomass (g)	Root biomass (g)	Total biomass (g)
1: Control	0.14 ± 0.02	0.11 ± 0.01	0.25 ± 0.02
2: [50%]	0.20 ± 0.04	0.08 ± 0.02	0.28 ± 0.05
3: [75%]	0.15 ± 0.02	0.10 ± 0.02	0.25 ± 0.03
4: [100%] standard	0.20 ± 0.03	0.09 ± 0.02	0.29 ± 0.05
5: [150%]	0.14 ± 0.02	0.07 ± 0.02	0.21 ± 0.04
6: [200%]	0.16 ± 0.02	0.08 ± 0.01	0.24 ± 0.03

7.3 Nitrogen and Carbon Accumulation

Total nitrogen and carbon accumulation in plant tissues is shown in Table 4. Nitrogen concentrations were not significantly different in leaf tissues ($p = 0.744$) or root tissues ($p = 0.51$) at the 0.05 level between treatments.

Table 4. Average leaf and root nitrogen and carbon concentrations (% of dry weight) in leaves and roots (n=6).

Treatment No.	Leaf %N	Leaf %C	Root %N	Root %C	Leaf N/C%	Root N/C%
1: Control	0.89 ±0.08	39.34 ±0.17	0.98 ±0.13	40.11 ±0.74	2.25 ±0.17	2.43 ±0.31
2: [50%]	0.81 ±0.04	36.46 ±1.17	0.83 ±0.07	40.48 ±0.95	2.21 ±0.07	2.06 ±0.14
3: [75%]	0.89 ±0.09	39.62 ±0.48	0.86 ±0.13	41.69 ±0.35	2.24 ±0.21	2.07 ±0.29
4: [100%] standard	0.85 ±0.03	40.13 ±0.29	1.03 ±0.13	42.44 ±0.25	2.11 ±0.08	2.43 ±0.30
5: [150%]	0.93 ±0.07	39.82 ±0.82	1.08 ±0.11	41.83 ±0.31	2.35 ±0.16	2.58 ±0.26
6: [200%]	0.84 ±0.03	39.54 ±0.77	1.11 ±0.14	41.30 ±0.92	2.11 ±0.04	2.68 ±0.33

8. DISCUSSION

The objectives of this experiment were to successfully cultivate *D. capensis*, and determine if a supplementary feeding treatment to the foliage using NH_4Cl provided any significant contribution in terms of biomass and nitrogen accumulation within the plant.

The cultivation of *D. capensis* was successful under the protocol used for this experiment. Plants grew to an average of 1.49g per plant across all of treatments. Compared to treatments with added fertilizer, the fact that plants grew as much in our experiment without using nutrient fertilizer (i.e. control plants), indicates that *D. capensis* has the ability to establish and grow at very low levels of nitrogen. This suggests that sources of nitrogen (and other nutrients) were obtained in sufficient amounts from the media to sustain growth, an observation also noted in the literature (Chapin and Pastor 1995; Adamec 2002). Owen and Lennon (1999) also showed that the tropical pitcher plant *Nepenthes alata* Blanco. could be grown in greenhouse conditions without the addition of fertilizer. Our result indicates that, under laboratory conditions and with a proper media, *D. capensis* can solely grow on its own photosynthetic carbon and root nutrient acquisition capabilities.

For the duration of the experiment, flower stalk production was observed in several plants for all treatments. A greater number of flower stalks were observed in plants under higher concentrations compared to that of lower concentration or the absence of fertilizer. These observations may suggest that flower production is linked to nutrient concentrations. However, the similarity in plant tissue nitrogen concentrations

and biomass in all treatments makes this suggestion very unlikely. Furthermore, *D. capensis* is known to repeatedly produce flower stalks throughout a growing season (D'Amato 1998). In addition, flower stalk abortion prior to flower production occurred in both high and low treatment concentrations. It has previously been documented that flowering frequency increases in some insectivorous plants with higher nutrition availability (Thoren and Karlsson 1998). However, with the addition of nutrients to *D. rotundifolia*, flower production decreased (Stewart and Nilsen 1991). This suggests is that these plants have specifically adapted to their habitat and vary in limitations and need for additional nutrient input. Seed production or seed viability was not tested in this experiment.

As noted in Table 2, there were differences in the average biomass between all treatments, however, none were statistically significant. This indicates that *D. capensis* did not benefit in biomass from supplementary nitrogen as control plants grew apparently as well as those receiving supplementary nitrogen. Chapin and Pastor (1995) also showed that *S. purpurea* did not differ in terms of biomass as compared to the control when supplemented with an NH_4Cl fertilizer into the pitchers. These results suggest three possibilities: 1) the concentration of NH_4Cl was not high enough to show effective results; 2) the fertilizer NH_4Cl is not effective in terms of biomass production and may require the presence and/or action of other nutrients which could lead to increased biomass or 3) the fertilizer NH_4Cl is not readily taken up by the absorbing mechanisms found on the leaves of *D. capensis*.

The last scenario has not been tested in other *Drosera* plants using an NH_4Cl fertilizer. However, Karlsson and Pate (1992) documented that two pygmy species of *Drosera* (*D. closterostigma* March. & Low. and *D. glanduligera* Lehm.) were unresponsive to a nutrient supplementation (Hoaglands) when applied to the roots. Trapping mechanisms of prey capture are known (Givnish 1989; D'Amato 1998; Slack 2000), however, the exact mechanism of enzymatic release and digestion involving chemical and physical signals is poorly understood. If chemical signals are involved, then we need to know what particular chemical(s) are involved and at what concentrations or levels they are required.

Zamora *et al.* (1997) found that *Pinguicula vallisneriifolia* did not increase in biomass under a nutrient solution fertilizer applied to the leaves but rather showed remarkable growth when fed live insect prey. These findings suggest that some species of insectivorous plants could require the capture of live prey rather than a supplementary nutrient spray application to stimulate enzymatic digestion.

The results found in our experiment contradict those of Adamec (2002), where he found the biomass of *D. capillaris, D. aliciae,* and *D. spathulata* increased 81 – 120% greater than that of the control plants when leaf fed with a nutrient supplementation. Similarly, Thoren and Karlsson (1998) documented that supplementary feeding by use of insect prey increased plant growth and biomass in three sub-arctic *Pinguicula* species (*P. alpina* L., *P. villosa* L., and *P. vulgaris* L.). This again may suggest that such insectivorous plants respond to natural prey far more efficiently than that of supplemental fertilization.

Nitrogen concentrations within the plants (Table 3) did not significantly differ between treatments. The results indicate that nitrogen levels within the plant were not affected by the supplementary NH_4Cl fertilizer applied to the leaves. Interestingly, the nitrogen and carbon percentages found in the shoot and root of *D. capensis* are similar to the concentrations found in most vascular plants (Raven *et al.* 1999). Adamec (2002) found that the final root or shoot nitrogen content in three *Drosera* species did not significantly differ from that of the controls even though their biomass did increase. This observation was also noted in three *Pinguicula* species studied by Thoren and Karlsson (1998), however, the only difference was these plants were supplementary fed with fruit flies (*Drosophila melanogaster*).

On the contrary, some nutritional experiments on insectivorous plants do suggest that nutrient concentrations do increase with supplementation. The study by Chapin and Pastor (1995) on *S. purpurea* showed a significantly higher amount of nitrogen content within plant tissue of fertilized plants (NH_4Cl fertilizer, similar to ours) than that of the controls and other treatments. The non-absorption of NH_4Cl through the leaves of *D. capensis* during our experiment may directly be correlated to trap and absorption mechanisms. As well, in other studies, the supplementary nitrogen source had been added in different forms and, in many cases, with other nutrients, suggesting a possible link between combinations of nutrients being more effective (Hanslin and Karlsson 1996; Adamec 2002; Adamec 1997; Zamora *et al.* 1997).

The results of our experiment indicated that foliar NH_4Cl fertilization had no significant effect on the growth of *D. capensis* and this raises additional points related to the physiology of this particular species. First, how can *D. capensis* successfully grow in

nutrient poor media without any additional nutrients? Second, what mechanisms are involved with nutrient uptake in the leaves of *D. capensis*?

It has been documented that insectivorous plants have evolved to live in naturally nutrient poor habitats where available nutrients such as nitrogen, phosphorus, potassium and many micronutrients are lacking or are not available in usable forms due to environmental conditions such as low pH, water logged soils and low decomposition rates (Adamec 1997; Ellison and Gotelli 2002). In our experiment, although nutrient levels in the media were minute, there were enough nutrients present to provide an adequate supply for significant gain in biomass. Presumably these conditions (including the light regime) were shown to be sufficient for the growth of *D. capensis*. Clearly, the ability to capture and utilize insects is not the primary source of nutrient acquisition in *D. capensis* (or perhaps other species of insectivorous plants), but is merely a mechanism to enhance nutrient capture or acquisition when available. Ellison and Gotelli (2002) showed that when the ambient nitrogen availability in the soil was high, *S. purpurea* did not produce or rarely produced its trapping structures compared to the phyllodia (keel leaves) which are more effective at photosynthesis than the pitchers. Similarly, Knight and Frost (1991) found the trap production in *Utricularia macrorhiza* Le Conte was directly related to the nutrient status of the water. This suggests that the production of traps in some carnivorous plant species is directly related to nutrient availability. In the case of *D. capensis*, the trapping mechanism is found on the photosynthetic leaf as one unit. Since the plant grew sufficiently in the experimental conditions of our study, the possibility of not producing digestive enzymes may be a prevalent trait under sufficient or optimal growing conditions. In addition if photosynthesis is optimal, testing the

quality of light or photosynthetic rates against the rate of insectivory in these unique plants should be further investigated. If these plants were to solely rely on insectivory for survival, they might have become extinct long ago. On a yearly basis, the insect capture rate of most insectivorous plants is usually fairly low compared to the amount of insects available. In many experiments attempting to quantify the benefits of insect nutrition, insectivorous plants have been over-supplemented with insects (Thoren and Karlsson 1998), which can mislead us to believe what the actual response to insect nutrition is in a natural habitat. We need to quantify the amount of prey capture first in order to fully understand the affects of insectivory. In addition, trapping becomes unlikely on larger types of insect prey resulting in a decrease in capture success (Gibson 1991).

Mechanisms involved in nutrient uptake in leaves of *D. capensis* are quite complex. Although poorly understood, it has been suggested that the process of digestion is initiated by a stimulant acting upon the stalked glands of the leaf. Such stimulation can occur naturally through insect contact or artificially by the addition of solid or liquid nutritive substance (Slack, 2000). However, the stimulant must still in some form trigger the movement action of the stalked glands to signal the process to start. To protect against unnecessary activation of digestion from rain water or dust, these glands have a mucilage envelope which surrounds the actual gland. Therefore, the stimulant must be able to diffuse through this mucilage and contact the actual gland (Pietropaolo and Pietropaolo 2002). This process of stimulation may explain why *D. capensis* in our experiment did not absorb the fertilizer from the treatments. Perhaps the nutrient is unable to penetrate the mucilage barrier to activate uptake by the sessile glands or the quantity of actual nutrient on the glands was insufficient. In addition, it is unknown

whether the mucilage of the glands has an affinity or repulsion towards some chemical compounds. It has been shown that high levels of ammonium may produce toxic effects in plants (de Graaf *et al.* 1998). Again, based on assumption, the *D. capensis* plants grown in this experiment may have had sufficient amounts of nitrogen in the tissue from other sources which possibly may deter the additional uptake to prevent toxicity.

In this experiment, it was shown that the insectivorous plant *D. capensis* did not significantly benefit from NH_4Cl fertilizer treatments. However, it was able to successfully grow and sometimes produce flower stalks without any additional nutrients. This experiment suggests that *D. capensis* can grow without the addition of nutrients from which that is present in the soil in its natural habitat or in our case, in the greenhouse trial. Through nutritional experiments using insectivorous plants, a variety of surprising results have indicated the diversity which surrounds the effects of nutrition on such plants. Difference in effects can only suggest a species specific regime.

Further experimentation is needed both in laboratory and field condition to provide a better understanding of insectivory in general and to quantify on a per species basis how nutritional supplementation may benefit the plant. Other tests should include several nutrients (N, P, K, and micronutrients) with and without stimulation of leaves and insect prey to justify the relationship between stimulation and nutrient uptake in both leaves and roots. In addition, studies directed towards the involvement of insectivory on the enhancement of photosynthesis should be explored. It should be recognized that the adaptation of plants to trap and utilize insect nutrients was a step forward in the evolution of plants. Many other non-insectivorous plants such as *Geranium viscosissimum* F. & M.

and *Potentilla arguta* Pursh. exhibit protocarnivory traits, which are morphological features such as sticky hairs similar to that of true carnivorous plants (Spomer 1999). These traits may indicate that such a mechanism of increasing mineral nutrition is more common among plants than first realized. I would conclude that insectivorous plants, given the nature of their nutrient poor habitats, the ability to survive without additional nutrients as shown in this experiment with *D. capensis*, could be considered opportunists taking advantage of an additional nutrient resource available in abundance in their habitat.

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